λ 1656·7 Å.U. was found on all the plates which Lyman gives as present in all metallic spark spectra in helium.* It was probably due to carbon from the decomposition of carbon monoxide given off from the wax joint.

As far as the writers can discover, none of the lines given for tellurium, molybdenum and zirconium have been measured hitherto for these elements. In the spectra of molybdenum and zirconium all the wave-lengths observed were of weak intensity. The radiations from tellurium, however, were stronger and their relative intensities are approximately those given in the Table. A reproduction of the spectrum of this element is given in Plate 2, A.

Note on Vacuum Grating Spectroscopy.

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[Plate 2, B.]

I. *Introduction.*

In the spectroscopy of the extreme ultra-violet region, it is necessary to work either with arcs *in vacuo* or with sparks in one or other of the gases hydrogen or helium. As all other gases are opaque to ultra-violet radiations of short wave-length, their use is precluded. With many of the elements, arcs are difficult to maintain in a vacuum, and consequently one is driven to the use of sparks in either one or other of the two gases mentioned.

Lyman,† in his brilliant researches, has shown us that, with hydrogen, it is possible to obtain spectra extending to about λ 900 Å.U. For radiations below this limit, it would appear, however, that hydrogen is more or less absorbing. With helium, on the other hand, the evidence available goes to show that this gas is transparent to radiations having wave-lengths as short as λ 400 Å.U. or λ 500 Å.U., and possibly shorter still. It would appear, then, that in the spectroscopy of the extreme ultra-violet, the procedure to be followed, which would permit of the most rapid progress being made, would be, in so far as the emission spectra are concerned, to work with a vacuum grating spectrograph, and to use an atmosphere of helium.

As regards the absorption spectra of the elements, helium also appears to be promising. From the work of Mackay and Ferguson,‡ it is known that arcs in helium can be struck and maintained for long periods between

* Lyman, 'Spectroscopy of the Extreme Ultra-violet,' p. 124.

† Lyman, 'Ast. Phys. Jour.,' p. 100 (March, 1916).

‡ Mackay and Ferguson, 'Franklin Inst. Journ.,' p. 209 (February, 1916).

non-vapourising electrodes, such as those of tungsten. This means that, if a vacuum grating spectrograph, provided with a lamp of the "Pointolite" type, be filled with helium to a suitable pressure, arcs can be struck in the gas, when the requisite voltages are applied, which will provide a radiation consisting of wave-lengths extending probably to near 400 λ Å.U. From Lyman's experiments, it is known that radiations are given out by helium of approximately this wave-length, and can be recorded. With such a source of illumination available, it should be possible, by interposing the vapours of elements between the arc and the grating of the spectrograph, to obtain the absorption spectrum of the elements vapourised.

The experience of different workers in this field has shown that, for success, extreme precautions must be taken to ensure that the vacuum grating spectrograph is kept free of water vapour and all such gases as oxygen, nitrogen, carbon monoxide, etc.

This means, in the first place, that the vacuum grating spectrograph should be designed so as to be as free as possible from all liability to leaks, and, in the second place, provision should be made to remove any traces of oxygen, nitrogen, or carbon monoxide, which are liberated from the electrodes by the establishment of the arc, or which exude from the walls of the spectrograph after the instrument has been filled with helium and while exposures are being made.

A description has already been given of a vacuum grating spectrograph, which was used by the writer in collaboration with Mr. R. J. Lang,* for studying the vacuum arc spectra of a few of the elements. With this apparatus, it was found that, while the spectrum of carbon, for example, was recorded so far down as λ 584 Å.U., it was only obtained when extreme care was taken to see that proper conditions obtained. Numerous difficulties and vexatious delays were experienced in making seals airtight and free from small leaks, chiefly because, in the design of the apparatus, a number of the seals were made between parts whose bearing surfaces were vertical. No provision was made in the apparatus, moreover, for removing exuded gases other than by pumping. The grating used, besides, was small, and this necessitated long exposures.

With a view to improving matters, the apparatus was redesigned, and provision was made not only for removing the exuded gases, but also for using a grating of any size, and for so arranging its carrier and its controls that adjustments could readily and easily be made. The description of this instrument follows:—

* McLennan and Lang, 'Roy. Soc. Proc.,' A, vol. 95, p. 258 (1919).

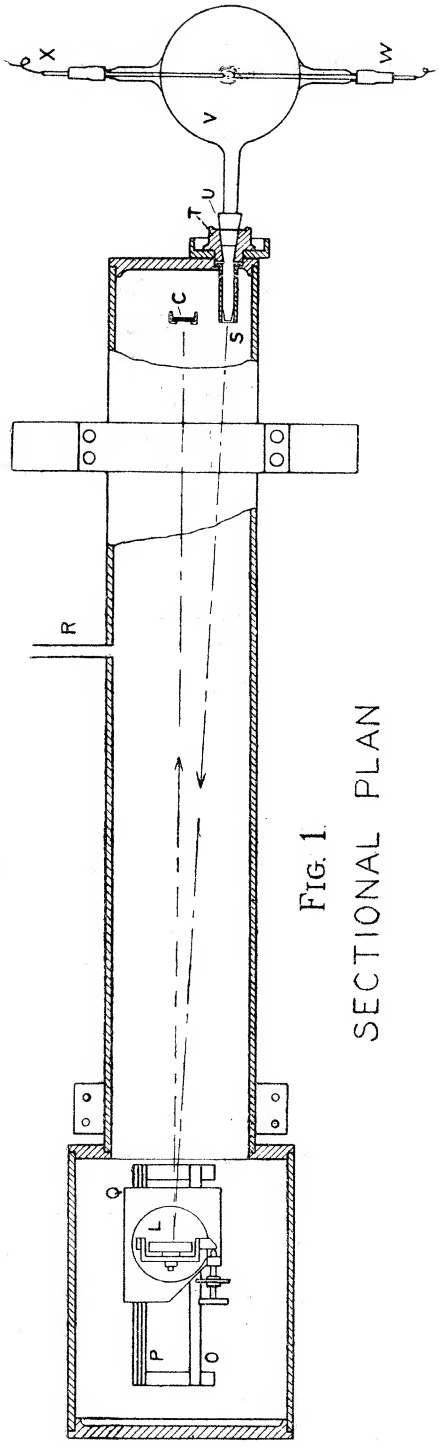

FIG. 1. SECTIONAL PLAN

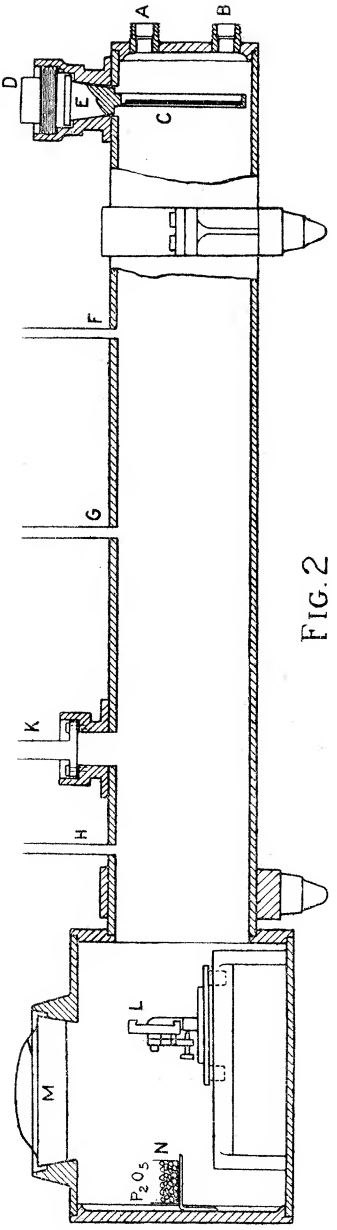

FIG. 2. SECTIONAL ELEVATION

II. *Vacuum Grating Spectrograph.*

A sectional plan of the apparatus is shown in fig. 1 and a sectional elevation in fig. 2. Figs. 3, 4, and 5 show enlarged sketches of the horizontal and vertical sections, and of the end view of the plate holder, slit, and observation windows. The various parts of the apparatus are designated as follows :—

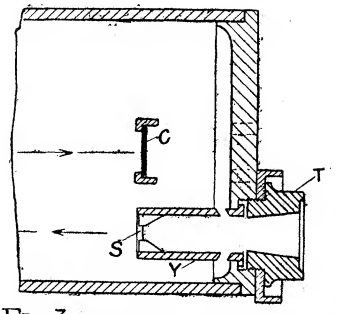

FIG. 3 HORIZONTAL SECTION

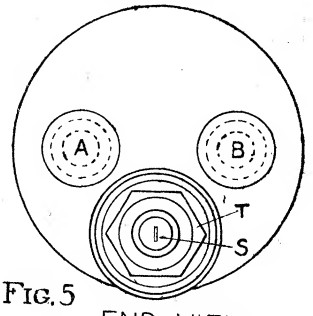

FIG. 5 END VIEW

A and B—glass windows used for focussing and lining up spectra; C—photographic plate, Schumann sensitised; D—screw plug fitted with leather washer; E—support for plate, with ground joint; F, G, and H—leads to cocoanut charcoal tubes; K—vacuum pump connection bolted to tube body, with screws and leather gasket; L—ruled diffraction grating—6273 lines per centimetre, ruling 7·8 cm., and 1 metre radius; M—cap over opening (to adjust grating), with ground joint; N—lead box containing P_2O_5 covered with glass wool; O and P—rails for carriage; Q—carriage; R—lead to discharge tube; S—slit; T—bushing threaded externally, fitted with leather gasket. Female ground joint at centre; U—male member, ground joint, attached to light-source container; V—glass bulb 17 cm. in diameter, with two arms to support electrodes; W—pure gum rubber tubing slipped over arm of bulb and electrode; X—electrode; Y—sleeve carrying slit holder.

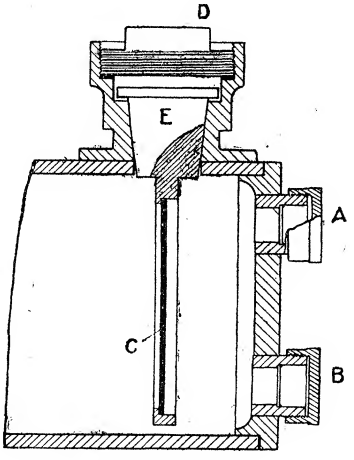

FIG. 4. VERTICAL SECTION

The spectrograph was designed for use with a grating having a radius of 1 metre, and it was therefore made about 130 cm. in length over all. The enlarged portion, which enclosed the grating, was 22 cm. in diameter and 30 cm. in length. The longer cylindrical portion of the apparatus had a diameter of 15 cm. As shown in the diagram, the opening above the grating was closed with a tinned

brass cap, M, which fitted into a casting with a tapered ground joint. This opening gave ready access to the grating for adjustment, and, when the cap was placed in position, with its bearing surfaces slightly smeared with "Airtite," and the groove shown in the figure filled with melted wax, a perfect seal was obtained. The exhaust pipe, K, was joined to the apparatus as shown, so that the junction could be made absolutely airtight by flowing over it a small quantity of melted wax. It was arranged that the grating should be placed in position with its rulings horizontal. For some preliminary experiments, a grating was used, with a ruling 5·4 cm. wide and 7·8 cm. long, and having 6273 lines per centimetre. The mount was provided with rails, which allowed 15 cm. travel for the grating, and with the usual adjusting devices for orientating the grating in various ways.

The plate-holder, C, was suspended vertically and was attached to a conical plug, E, for support. This plug carried a guide for ensuring its being inserted correctly in position, and it was also provided with slits (not shown in the diagram), in which could be inserted two thin brass strips for screening off light from the photographic plate when the plate-holder was carried from and to the developing chamber.

When the plate-holder was in position, a threaded plug, D, provided with a leather washer, closed the opening, and an absolutely airtight joint was made by filling up with melted wax the groove made above the threaded portion of D. The glass windows at A and B were permanently fastened into the apparatus with sealing-wax and were used for observing the central image of the slit while adjusting the grating. These windows were provided with removable caps for cutting off extraneous light while exposures were being made. The slit, S, was carried by a sleeve, which could be inserted, rotated, or removed at will. When the slit was properly adjusted, the bushing, T, was screwed in and permanently sealed to the apparatus with hard wax. The brass tubes, F, G, and H, led to three cocoanut charcoal tubes, which during exposures were immersed in liquid air. A fourth tube, R, led to a Geissler tube, which, when excited by a small induction coil, was used to make observations on the pressure of the gas in the spectrograph.

In operating, the spectrograph gases were removed by means of two Trimount oil-sealed pumps, in series, driven by individual motors. These pumps were found to be highly efficient, a green fluorescence vacuum being obtainable with them in about 15 minutes.

With the grating described above, it was found that in the first order the dispersion was such that a spectrum extending from $\lambda = 0$ Å.U. to $\lambda = 2000$ Å.U. covered about 5 inches of the photographic plate. It was possible, therefore, to make observation over this range with but a single setting.

In adjusting the grating and slit, a plate coated with anthracene was inserted in the plate-holder and the light from a spark between aluminium terminals was used for illumination. As the distance between the centres of the two observation windows was about 5 inches, the procedure followed was to adjust the grating so that the bright central image could be seen either through the lower or the upper window. When this condition obtained, the illumination of the anthracene screen by the wave-length $\lambda = 1854$ Å.U. could also then be seen as well through the other window if the orientation of the grating was correct. Fine focussing of the spectrum could be made by moving the mount of the grating with an adjusting screw slightly forward or back on the rails.

III. *Observations.*

When it was seen that the spectrograph from a mechanical and an operating point of view was satisfactory, some preliminary experiments were made with a sparking chamber such as that shown in fig. 1. The lamp and spectrograph were highly exhausted, washed out several times with charcoal-purified helium, and finally filled with this gas. The gas inlet valve was then closed and the charcoal tubes, attached at F, G, and H, were immersed in liquid air to take up any oxygen, nitrogen, or carbon monoxide liberated from the electrodes or from the walls of the apparatus. In these preliminary experiments it was found that in the visible portion of the spectrum the helium lines came out with strong intensity. In the ultra-violet region, however, there appeared on the photographic plates a series of gas lines in addition to those which were known to be due to the metals used.

It was then decided to make a special study of the spectrum obtainable from an arc in helium between tungsten terminals, in order to pick out the lines which one could definitely ascribe to helium itself. For this purpose the lamp shown in fig. 6 was designed.

Connection between the lamp and the spectrograph was made by means of the brass piece, E, which was sealed to the lamp by means of Khotinsky wax. This piece, E, as shown, was provided with a tapered end, which fitted, after careful grinding, very closely into its corresponding bushing, T, attached to the spectrograph. This was the only joint in the apparatus requiring to be frequently broken where the bearing surfaces were not horizontal. It was found, however, on account of the surfaces being ground to a good fit, that a slight smearing of "Airtite" made a perfectly gas-tight union.

N and R were two beads of tungsten, carried by two slender tungsten rods, which were carried by wires sealed into the glass stoppers F and G. C, H′ was a glass tube filled with cocoanut charcoal covered with a wad of glass-wool.

J was a coil of fine tungsten wire, which formed part of the heating circuit, O, J, P. In operating the lamp, both it and the spectrograph were filled with purified helium through the tap, D, to a pressure of from 30 cm. to 40 cm. of mercury. Liquid air was then placed about the charcoal tube, H′, and about those attached to the spectrograph at F, G, and H, fig. 1. F, fig. 6, was joined to the positive terminal of a 110-volt D.C. circuit, and O to the negative terminal of the same circuit. The circuit included, of course, a variable

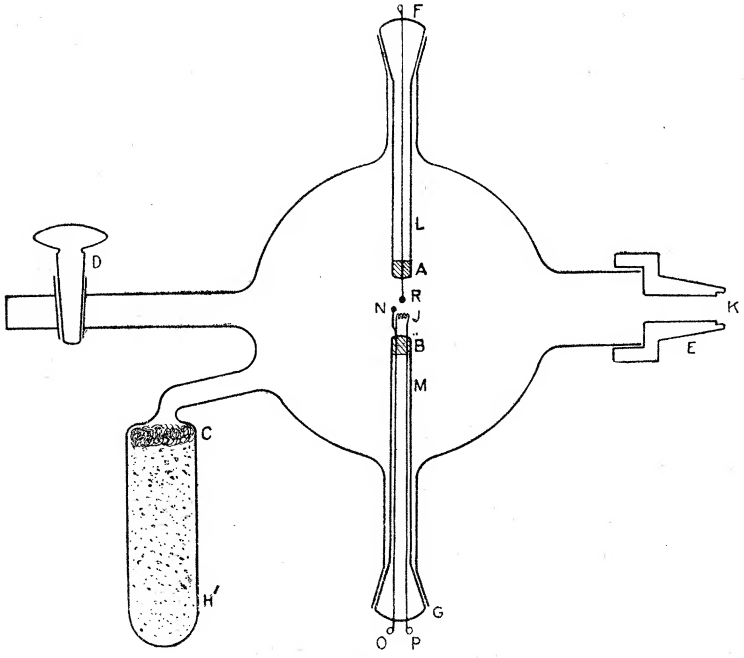

Fig. 6.

rheostat. The heating circuit, O, J, P, was provided with current from an insulated battery, and it was found that, at the pressures cited, as soon as J became incandescent the arc struck between J and R, and then finally between N and R. At this point the auxiliary heating battery was cut off and the arc persisted without it. At the pressures used, it was found quite easy to establish and maintain for hours arcs in helium with distances as great as 5 mm. or 6 mm. between the two tungsten beads, N and R. Tests made from time to time on these helium arcs showed a potential drop between the terminals of 45 volts when a current of 4·6 ampères was passing.

IV. *Results.*

A number of plates were taken of the spectra of the helium arcs established in the manner described, and all showed lines due to hydrogen

and possibly to carbon monoxide. A list of the wave-length determinations from measurements made on a number of plates is given in Table I, and a reproduction of the spectrum of the helium arc is shown in Plate 1. In the visible portion of the spectrum the helium lines came out with strong intensity.

Table I.—Helium Arc Spectrum.

Wave-length in Å.U.	Intensity.	Lyman's results.		Remarks.
		Wave-length in Å.U.	Origin suggested by Lyman.*	
1988·4	1			
1979·8	V.F.			
1975·6	V.F.			
1963·4	V.F.			
1952·1	1			
1932·4	15			
1921·3	V.F.	—	—	Due to carbon. McL., A. and F., 1930·5.† McL. and L., 1933·0.‡
1913·0	V.F.			
1904·0	1			
1884·2	1			
1875·2	1			
1863·3	3			
1855·0	1			
1848·7	V.F.			
1842·5	1			
1827·0	V.F.			
1812·6	V.F.	—	—	Carbon? McL., A. and F., 1811·9.
1795·9	1			
1786·9	V.F.	1785·1	CO?	
1777·3	1			
1754·0	1			
1745·6	4	—	—	Silicon?
1732·2	V.F.			
1716·0	2	1656·8	Uncertain—Strong in He discharge	Due to carbon. McL., A. and F., 1656·9.
1658·2	15	1633·7		
1633·9	V.F.			
1601·9	1	1602·0	H	
1561·8	12	1561·2	H (Uncertain—Strong in He discharge)	Due to carbon. McL., A. and F., 1561·2.
1552·8	V.F.	1553·0	H	
1542·9	V.F.			
1534·4	V.F.	1535·0	H	
1516·4	V.F.	1516·4	H	
1506·8	V.F.	1506·6	H	
1494·6	9	1495·5	H	
1483·2	V.F.	1483·7	H	
1464·0	2	1463·9	H	
1412·4	V.F.	1413·0	H	
1358·2	V.F.	1358·2	H	
1335·4	14	1336·1	H	

* Lyman, "The Spectroscopy of the extreme Ultra-Violet," pp. 109–112, 124; 'The Ast. Phys. Jour.,' vol. 43, No. 2, p. 89 (1916); 'Proc. Amer. Acad. Arts and Sci.,' vol. 45, No. 10, March, 1910.

† McLennan, Ainslie, and Fuller, 'Roy. Soc. Proc.,' A, vol. 95, p. 316 (1919).

‡ McLennan and Lang, 'Roy. Soc. Proc.,' A, vol. 95, p. 358 (1919).

Table I—*continued.*

Wave-length in Å.U.	Intensity.	Lyman's results.		Remarks.
		Wave-length in Å.U.	Origin suggested by Lyman.*	
1329·0	13	1329·3	H	Uncertain origin.
1297·5	16	1297·4	H	
1277·6	4	1277·1	H	
1260·9	2	1261·9	H	
1242·7	1	1241·5	H	
1215·7	15	1216·0	H*	First members of Ritz series.
1199·7	13	1199·8	H or He	
1168·2	1	1169·2	H	
1151·9	1	1151·2	H	
1144·0	V.F.	1145·5	H	
1134·7	12	1134·7	H or He	
1085·1	1	1086·1	H or He†	
1037·3	2	1037·0	H or He	
1025·8	3	1026·0	H*	Second member of Ritz series.

* Lyman, 'Nature,' No. 2622, vol. 104, p. 565 (January 29, 1920).

† Lyman considers this line to be due to an impurity, 'Nature,' p. 565 (January 29, 1920).

An attempt was made to identify the wave-lengths, and suggestions as to their probable origin are given in the Table. Between $\lambda = 1000$ Å.U. and $\lambda = 1700$ Å.U., it would seem from Lyman's results that the majority of the wave-lengths was due to hydrogen. The two wave-lengths $\lambda = 1216$ Å.U. and $\lambda = 1026$ Å.U. constitute the first and second members of the principal series of the hydrogen spectrum predicted by Ritz, calculated by Bohr, and identified by Lyman. These, it will be seen, are among the more intense wave-lengths recorded. The wave-length $\lambda = 1329{\cdot}0$ Å.U. was among the strongest recorded, and appears to be of uncertain origin. Lyman gives a wave-length at $\lambda = 1329{\cdot}3$ Å.U. for hydrogen, but it appears to have come out on his plates with an intensity much less than it did on the plates obtained in this investigation. The wave-lengths $\lambda = 1561{\cdot}8$ Å.U., $\lambda = 1658{\cdot}2$ Å.U., and $\lambda = 1932{\cdot}4$ Å.U., are evidently due to carbon possibly having its origin in the tap grease used for making the joints gas-tight. For the range between $\lambda = 2000$ Å.U. and $\lambda = 1700$ Å.U., it will be seen that the spectrum consisted, with a few exceptions, of a series of wave-lengths of feeble intensity. These would not appear to have been due to hydrogen, but may have had their origin in the vapour of tungsten, which probably was present to a slight extent in the arcs. No indication was obtained of the presence of the wave-length $\lambda = 1640$ Å.U., which Lyman found could be obtained from helium. This was no doubt due to the fact that the arcing potential used in the experiments was only 45 volts.

An arcing potential of over 80 volts, on the Bohr theory, would be required to bring out this wave-length in the radiation emitted. The shortest wave-length recorded, it will be seen, came at $\lambda = 1025{\cdot}8$ Å.U., but, while this is so, it should be stated here that, on all the plates, indications were obtained of a faint continuous spectrum, extending to well below $\lambda = 500$ Å.U. As the two tungsten beads, N and R, were highly incandescent during the operation of the arc, it may be that this continuous spectrum had its origin in the radiations emitted by them.

From the results of the investigation, it would appear that, in order to obtain the spectrum of helium in the extreme ultra-violet region with arcs between non-vapourisable electrodes, very special precautions will have to be taken to remove all traces of hydrogen from the helium in the spectrograph.

To do this, it would probably be necessary to admit small quantities of oxygen to the spectrograph from time to time, and to remove the excess oxygen by means of the charcoal tubes. It would probably prove more expeditious, however, to adopt a suggestion recently made by Lord Rayleigh, to cause the helium in the spectrograph to circulate in a closed cycle, part of the circuit being external to the spectrograph, and having included in it a tube, filled with charcoal, maintained at the temperature of liquid air, as well as others suitably equipped for getting rid of the hydrogen. Such a circulatory system could be operated for any time desired, and its use would enable one to raise the helium to the highest possible degree of purity.

The adoption of such special precautions to get rid of the hydrogen are all the more necessary if a pure spectrum of helium is to be obtained, for it has been shown that, in part of the ultra-violet region at least, the wave-lengths emitted by helium should be close to analogous ones emitted by hydrogen.

In view of the fact that the shortest wave-length recorded in this investigation was $\lambda = 1025{\cdot}8$ Å.U., it should be noted that the potential fall between the electrodes in the arc was only 45 volts. To bring out the shortest wave-lengths obtainable from helium, it would be necessary to arrange matters so that the drop in potential was considerably increased.

In conclusion, the writer wishes to acknowledge his indebtedness to Mr. A. Sinclair for assistance in constructing the spectrograph, and to Mr. P. H. Petrie for help in taking the spectrograms.